IN-EAR SPEAKER HYBRID AUDIO TRANSPARENCY SYSTEM

FIELD

[0001] Embodiments described herein relate to an in-ear speaker (e.g., an earbud). More particularly, the embodiments described herein relate to an insertable in-ear speaker that is configured as a hybrid, audio transparency system. Other embodiments are also described.

BACKGROUND INFORMATION

[0002] Wired or wireless in-ear speakers (e.g., earbuds) deliver sounds to one or more ears of a user (also referred to here as a listener or wearer) of such an in-ear speaker. One type of in-ear speaker is designed to be closely coupled to a user's ear canal, referred to as an "insertable in-ear speaker". This type in-ear speaker can be placed inside a concha at the entrance of the user's ear canal or can be inserted into the ear canal to block its entrance.

[0003] Generally there are two mutually exclusive types of insertable in-ear speakers, which are as follows: (i) an insertable in-ear speaker that fully seals an ear canal (hereinafter "sealable insertable in-ear speakers"); and (ii) an insertable in-ear speaker that is intentionally designed to allow some sounds from the ambient environment to leak into the user's ear canal during use (hereinafter "leaky insertable in-ear speakers"). Leaky insertable in-ear speakers provide better audio transparency than sealable insertable in-ear speakers. Nevertheless, sounds from the ambient environment may be unwanted to a user. To avoid this scenario, sealable insertable in-ear speakers may be used by the user. Sealable insertable in-ear speakers have some shortcomings. Users of these types of in-ear speakers can be subjected to unwanted sounds resulting from an occlusion effect (OE) during use (e.g., during telephone calls, while running, etc.). Also, a sealable insertable in-ear speaker can prevent its user from perceiving sounds from the ambient environment.

SUMMARY

[0004] Embodiments of an insertable in-ear speaker that is configured as a hybrid transparency system are described. Such an in-ear speaker can assist with at least one of: (i) improving a user's isolation from sounds from the ambient environment by preventing those sounds from entering the ear canal; or (ii) improving a user's perception of audio transparency by enabling delivery of sounds from the ambient environment to the ear canal.

[0005] An insertable in-ear speaker is configured as a hybrid transparency system that combines the use of an active, venting or acoustic pass valve, with an ambient sound pickup and production (also referred to here as ambient sound augmentation) system. A user content sound system, e.g., having an electro-acoustic transducer (speaker driver) that is integrated within a housing of the in-ear speaker, generates user content sound, in accordance with a first audio signal, e.g., containing user content such as an on-going telephone conversation between the wearer of the in-ear speaker and a far end user, music playback, or playback of another audio-containing work. The user content sound is produced for delivery into an ear canal of a wearer of the in-ear speaker. The in-ear speaker may be a sealing type, which seals the ear canal. The in-ear speaker housing also contains the venting or acoustic pass valve which can be configured (alternately) into a state in which it enables sound waves inside the ear canal to travel to an ambient environment, and into another state in which it restricts the sound waves from traveling to the ambient environment. An external microphone is configured to produce a second audio signal (ambient content signal) from sound waves in the ambient environment. The external microphone may also be integrated into the in-ear speaker housing, in such a way that it becomes positioned in a concha, close to the ear canal, when the in-ear speaker is worn; it is referred to as "external" since its primary acoustic input port may be facing outward into the ambient environment. There is also logic circuitry, e.g., as part of a programmed processor, which may or may not be installed within the in-ear speaker housing, that is configured to implement an equalizer (e.g., a spectral shaping digital filter) that adjusts a frequency component of the second audio signal (representing the ambient sound as picked up by the external microphone). The adjustment can be based on an equalization profile of the ear canal. After the adjustment, the second audio signal can be delivered to the ear canal by being converted into sound waves, e.g., by being combined with the second audio signal and then converted into sound using the user content sound system, or the same electro-acoustic transducer that is being used to convert the user content into sound.

[0006] The equalization profile may be a collection of one or more acoustic characteristics or properties, associated with the ear canal. These may include, but are not limited to, a sound pressure associated with the ear canal; a particle velocity associated with the ear canal; a particle displacement associated with the ear canal; an acoustic intensity associated with the ear canal; an acoustic power associated with the ear canal; a sound energy associated with the ear canal; a sound energy density associated with the ear canal; a sound exposure associated with the ear canal; an acoustic impedance associated with the ear canal; an audio frequency associated with the ear canal; or a transmission loss associated with the ear canal. For one embodiment, the one or more acoustic properties are determined by an ear canal identification module, based on an acoustic test signal picked up by a microphone of the in-ear speaker, while the in-ear speaker is being worn by its end user. In another embodiment, the one or more acoustic properties are computed based on an average of multiple acoustic properties associated with multiple ear canals, e.g., as determined in a laboratory setting.

[0007] For one embodiment, the logic is further configured to activate or trigger operation of an ambient sound augmentation system that uses the external microphone, only when the valve is enabling sound waves of the first audio signal inside the ear canal to travel to the ambient environment, e.g., the valve is in its open state. In one embodiment, the in-ear speaker that is configured as a hybrid transparency system also operates as part of an active noise control (ANC) system that performs acoustic noise cancellation upon any unwanted sound in the ear canal. The ANC system may also be used to compute one or more acoustic properties of the ear canal that are part of the equalization profile (which is used to configure the spectral shaping function of the equalizer.)

[0008] For one embodiment, a computer implemented method of using an insertable in-ear speaker as a hybrid